

Motor Control Blockset™

Sensorless Field-Oriented Control (FOC) of PMSM
Using Renesas® MCK-RA6T2 Motor Control Kit



MATLAB®

R2024a



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Sensorless Field-Oriented Control (FOC) of PMSM Using Renesas® MCK-RA6T2 Motor Control Kit

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Revision History

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About This Example

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Introduction

This example implements V/F (open-loop or scalar) and field-oriented control (FOC) techniques to control the speed of a three-phase permanent magnet synchronous motor (PMSM). The FOC speed control algorithm that the example implements uses the Extended EMF Observer block to obtain realtime rotor position using sensorless position estimation.

In addition to simulation of the V/F and FOC control algorithms, the example supports deployment of these algorithms on the Renesas MCK-RA6T2 motor control kit.

You can use the kit to perform motor control evaluation and debugging safely with a communication board that isolates PC and CPU board electrically. The kit has these features:

- RA6T2 motor control MCU
- Inverter board for 3-phase BLDC motor (with 48V/10A rating)
- On-board debugger for flash programming of MCU
- Overcurrent detection
- Support for one-shunt/three-shunt current sensing
- Support for position sensors

For more information about this kit, see MCK-RA6T2 Renesas Flexible Motor Control Kit for RA6T2 MCU Group.

Hardware Requirements

This section lists the hardware requirements to run the example:

- 1** Renesas MCK-RA6T2 motor control kit (RTK0EMA270S00020BJ) that includes these peripherals:
 - Inverter board (RTK0EM0000B12020BJ)
 - Controller board (RTK0EMA270C00000BJ)
 - Brushless DC (BLDC) motor (R42BLD30L3) with rated voltage of 36 V and rated current of 1.67 A
 - USB cable
- 2** 24V power supply

For detailed specifications of the MCK-RA6T2 motor control kit, see MCK-RA6T2 User's Manual.

Software Requirements

This section lists the software products from MathWorks® and Renesas that you need to simulate and run the example models on the MCK-RA6T2 motor control kit.

Required MathWorks Products

To simulate the example model:

- MATLAB®
- Simulink®
- Motor Control Blockset
- Stateflow®

To generate code and deploy the example model:

- MATLAB
- Simulink
- Motor Control Blockset
- Stateflow
- Embedded Coder®
- Simulink Coder™
- MATLAB Coder

Required Renesas Products

- e² studio (an integrated development environment (IDE) for Renesas MCUs)

Contents of Downloaded ZIP Folder

The ZIP folder that you downloaded from the GitHub® repository, includes:

- 1 MATLAB project package for V/F and FOC control algorithms, which includes the following files and folders:

Folder Name	Description
code	Contains generated code (if any).
components	Contains Simulink model components for V/F and FOC control algorithms.
data	Contains Simulink data dictionary file (motorControlData.slidd).
model	Contains Simulink models for V/F and FOC algorithms that support both simulation and code generation.
resources	Contains MATLAB project resource data and logs.
script	Contains initialization and utility scripts to use the Simulink models.
shortcuts	Contains shortcut utility scripts for the MATLAB project window.
work	Contains any additional data or utility files (if any).

File Name	Description
McbRenesas.prj	File that launches the MATLAB project window.

- 2 Driver package for the MCK-RA6T2 motor control kit, which includes the following folder:

Folder Name	Description
e2StudioProject	<p>Contains the control algorithm code along with driver package for the MCK-RA6T2 motor control kit (RTK0EMA270S00020BJ).</p> <p>The software e² studio uses this folder to launch the Renesas hardware project for MCK-RA6T2 motor control kit.</p> <p>The src directory available inside this folder contains the control algorithm code generated by the MATLAB project window.</p>

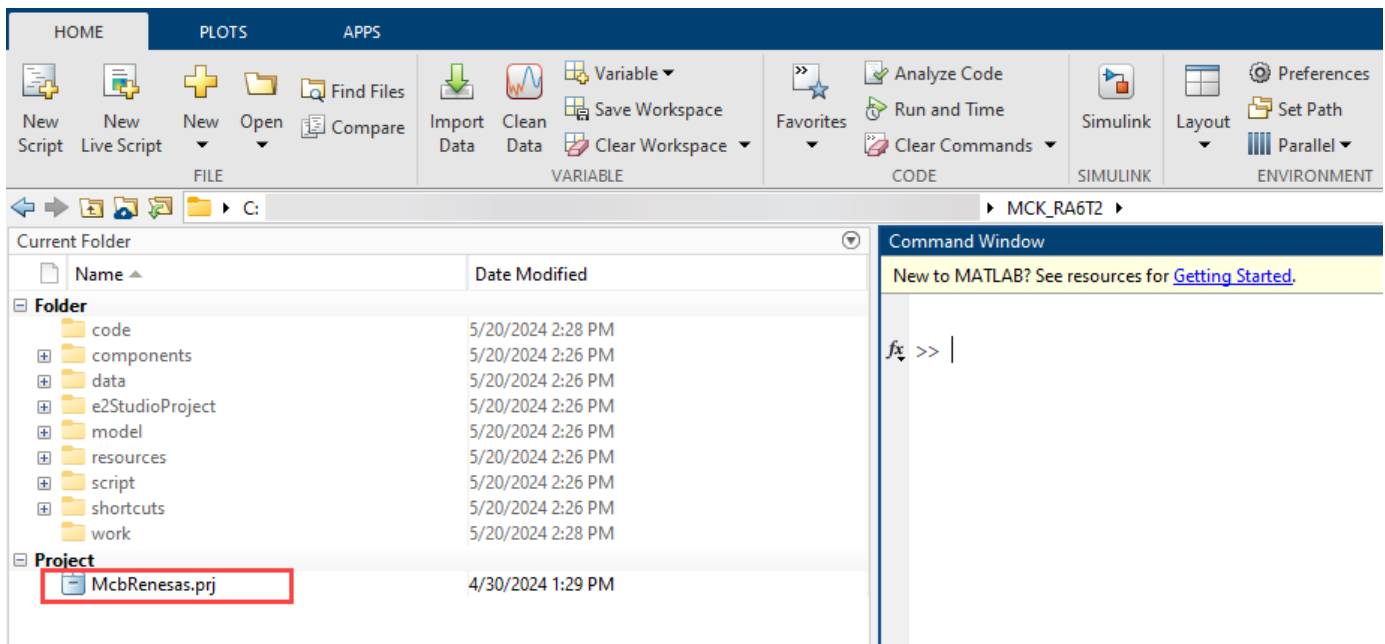
V/F (Open-Loop or Scalar) Control of PMSM Using Renesas Hardware

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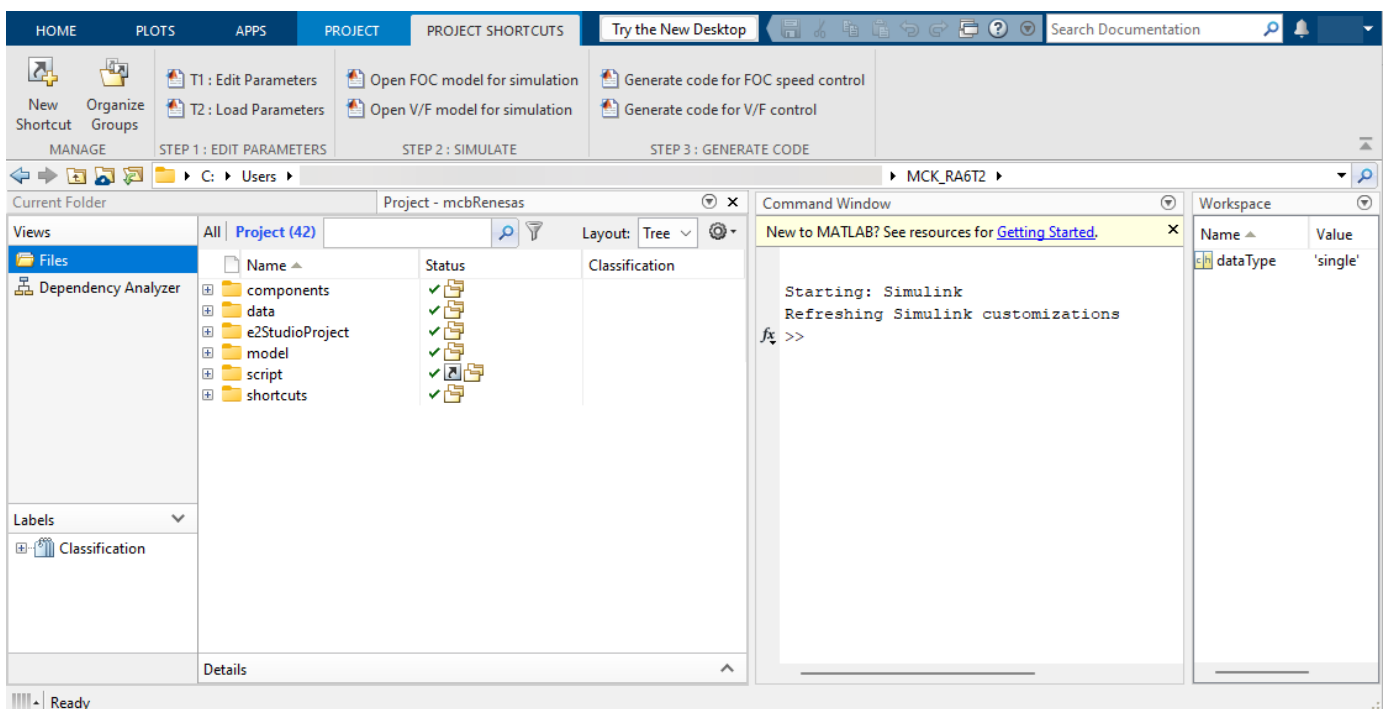
Open MATLAB Project

Follow these steps to open the MATLAB project associated with this example:

- 1 Unzip the MCK_RA6T2.zip folder that you downloaded from the GitHub repository.
- 2 Open MATLAB and navigate to the folder you unzipped in step 1.



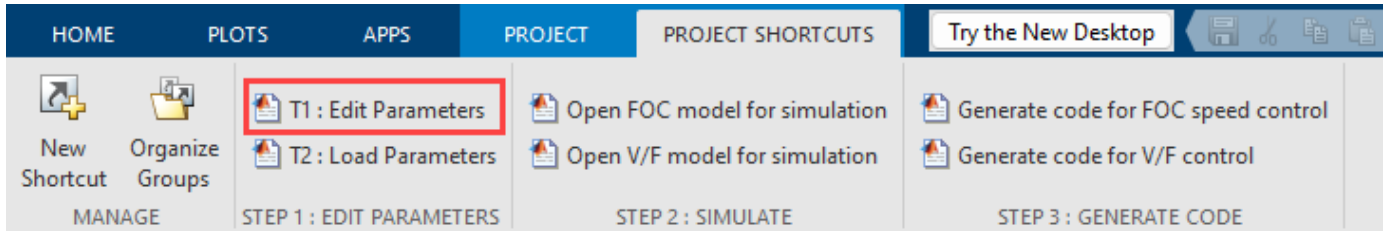
- 3 Double-click the file McbRenesas.prj to open the following MATLAB project window.



Update Motor and Inverter Parameters

The prerequisite to simulating or deploying the Simulink model containing V/F control algorithm is to edit the motor and inverter parameters and load them to MATLAB base workspace. Follow these steps to update and load the parameters:

- 1 In the **Project Shortcuts** tab of the MATLAB project window, click the **T1: Edit Parameters** shortcut button to open the model initialization script `EnterParameters.m`.



The Simulink model uses this script to obtain the motor, inverter, and other parameter values, which it uses to compute the derived parameters.

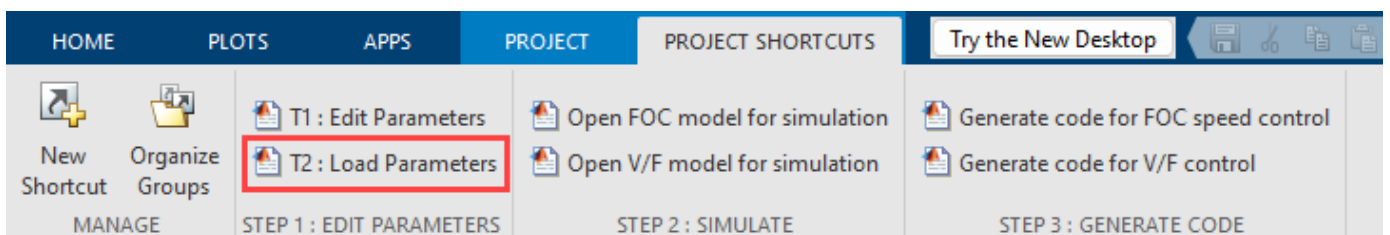
- 2 Update the following sections of the model initialization script `EnterParameters.m`:
 - **Control Loop Frequencies**
 - **Inverter Parameters**
 - **Motor Parameters**

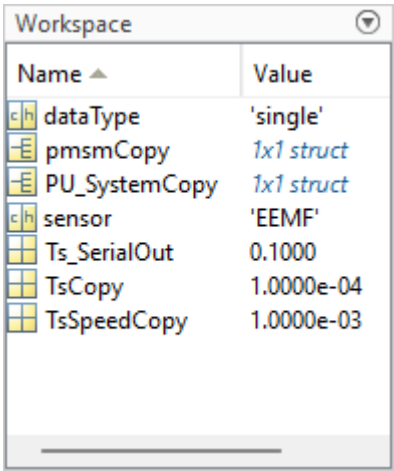
```

Current Folder      Project - mcbRenesas      Editor - EnterParameters.m
EnterParameters.m  +
1  %% Control loop frequencies
2  fCurrentControl    = 10e3;      % Hz
3  fSpeedControl      = fCurrentControl/10;    % Hz
4
5  target.PWM_frequency = 10e3;    % Hz          % The frequency configuration must be done in driver code too
6
7  %% Inverter Parameters
8  inverter.V_dc      = 24;        % V
9  inverter.ISenseMax = 8.25;      % A          % Maximum current sensed by inverter
10 inverter.R_board    = 0.0033;   % ohm        % Rds_ON + Rshunt/3
11
12 %% Motor Parameters
13 pmsm.p              = 4;        %          % Pole pairs
14 pmsm.I_rated        = 1.6;      % A
15 pmsm.N_rated        = 3500;     % RPM
16 pmsm.T_rated        = 0.1;      % Nm
17 pmsm.QEPSlits       = 1000;     %          % Quadrature encoder slits
18 pmsm.Rs              = 0.75;    % ohm
19 pmsm.Ld              = 0.5e-3;   % H
20 pmsm.Lq              = 0.5e-3;   % H
21 pmsm.Ke              = 7;       % Vpk_LL/kRPM
22 pmsm.J               = 8e-6;     % Kg-m2
23 pmsm.B               = 8e-5;     % Kg-m2/s
24 pmsm.V_boost         = 0.15;     % PU volt
25
26 %% Sensor selection
27 sensor = 'EEMF';           % 'Encoder' , 'EEMF'
28
29 %% Derived Parameters
30 T_pwm = 1/target.PWM_frequency;
31 Ts = 1/fCurrentControl;
32 Ts_speed = 1/fSpeedControl;
33 Ts_motor = Ts/2;
34
35 Ts_SerialOut = 0.1;        % Required only for UART
36
37 pmsm.FluxPM = (pmsm.Ke)/(sqrt(3)*2*pi*1000*pmsm.p/60);
38 pmsm.N_base = mcb_getBaseSpeed(pmsm,inverter);
39 PU_System   = mcb_SetPUSystem(pmsm,inverter);
40 PI_params   = mcb_SetControllerParameters(pmsm,inverter,PU_System,T_pwm,Ts,Ts_speed);
41
42 % Create copies for EEMF block as the parameters are not tunable

```

- 3 Click **Save** to save the file `EnterParameters.m`.
- 4 Switch to the MATLAB project window and navigate to the **Project Shortcuts** tab.
- 5 Click the **T2: Load Parameters** shortcut button to:
 - Compute derived parameters using the data available in the model initialization script.
 - Update all parameters to the Simulink data dictionary `motorControlData.sldd`.
 - Load necessary parameters from Simulink data dictionary to the MATLAB base workspace.





The screenshot shows the MATLAB Workspace window with a table of variables. The table has two columns: 'Name' and 'Value'. The variables listed are: dataType (single), pmsmCopy (1x1 struct), PU_SystemCopy (1x1 struct), sensor (EEMF), Ts_SerialOut (0.1000), TsCopy (1.0000e-04), and TsSpeedCopy (1.0000e-03). Each row has a small icon to its left, and the table is scrollable.

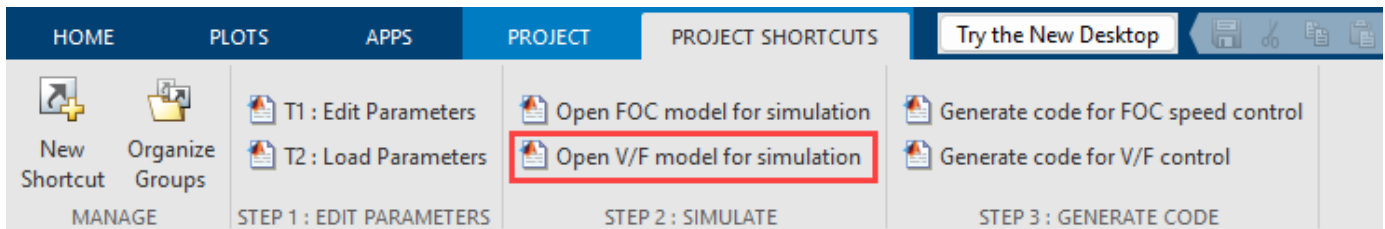
Name ▲	Value
dataType	'single'
pmsmCopy	1x1 struct
PU_SystemCopy	1x1 struct
sensor	'EEMF'
Ts_SerialOut	0.1000
TsCopy	1.0000e-04
TsSpeedCopy	1.0000e-03

Note The shortcut **T2: Load Parameters** loads only the necessary parameters to the base workspace. The Simulink model reads the other parameters directly from the Simulink data dictionary.

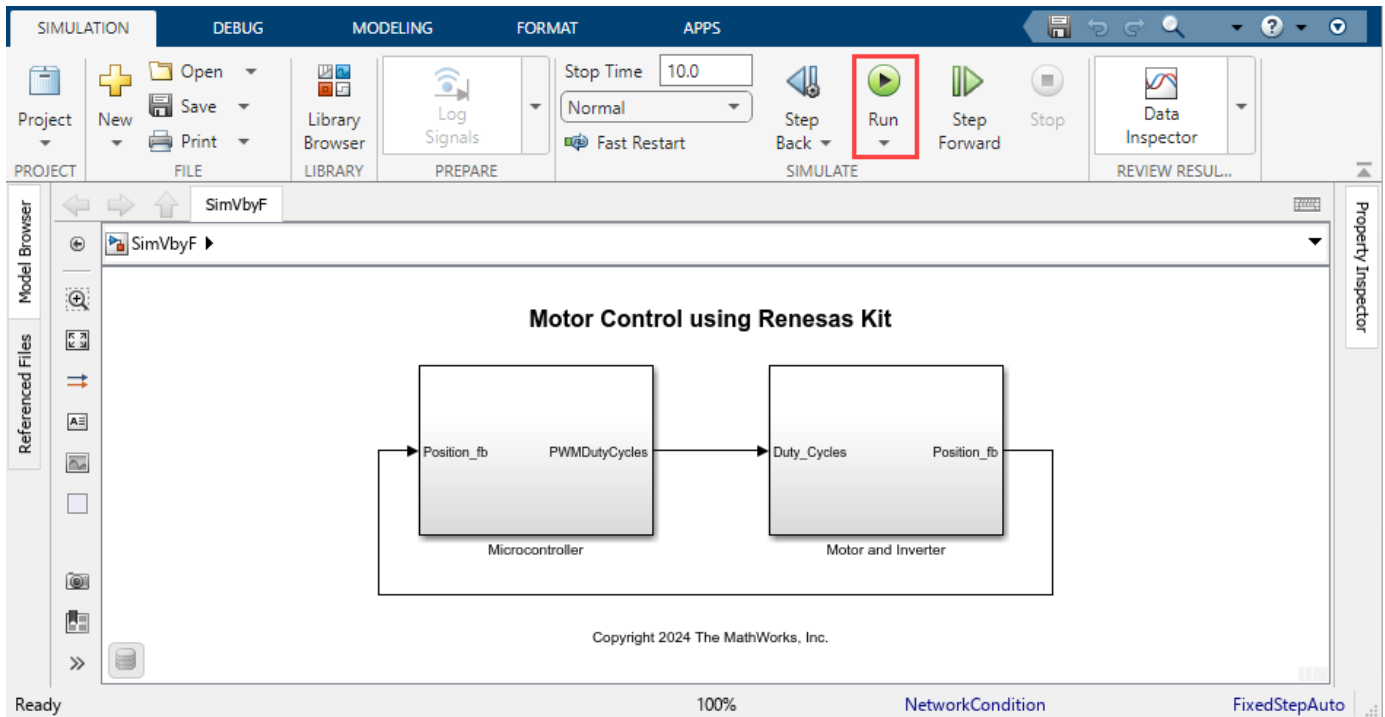
Simulate Model Containing V/F Control Algorithm

This example supports simulation. Follow these steps to simulate the Simulink model containing the V/F control algorithm.

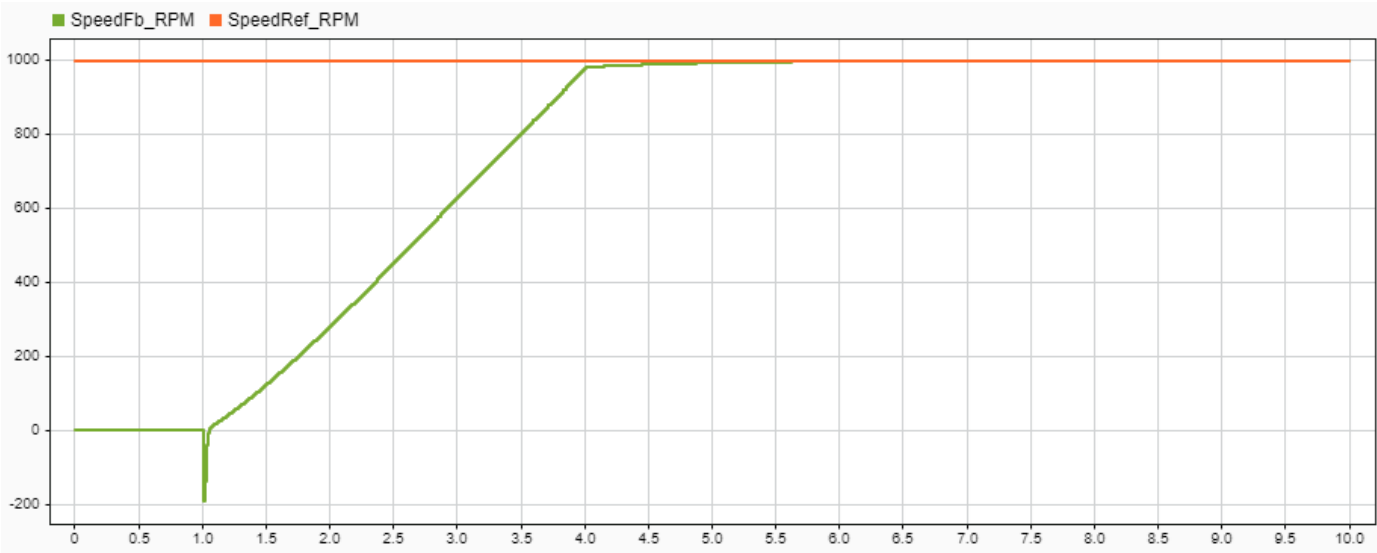
- 1 Ensure that you edit the motor and inverter parameters and load them to the MATLAB base workspace. For details, see the section Update Motor and Inverter Parameters.
- 2 In the **Project Shortcuts** tab of the MATLAB project window, click the **Open V/F model for simulation** shortcut button to open the Simulink model `SimVbyF.slx` containing the V/F control algorithm.



- 3 Click **Run** on the **Simulation** tab to simulate the model.



- 4 Click **Data Inspector** on the **Simulation** tab to view and analyze the simulation results.

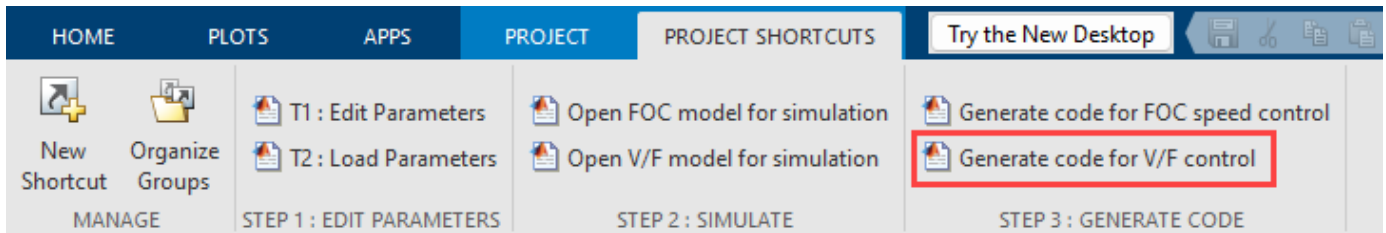


Generate Code for V/F Control Algorithm

This section explains how to use the Simulink model `SimVbyF.slx` to generate code for the V/F control algorithm.

Follow these steps to generate the code:

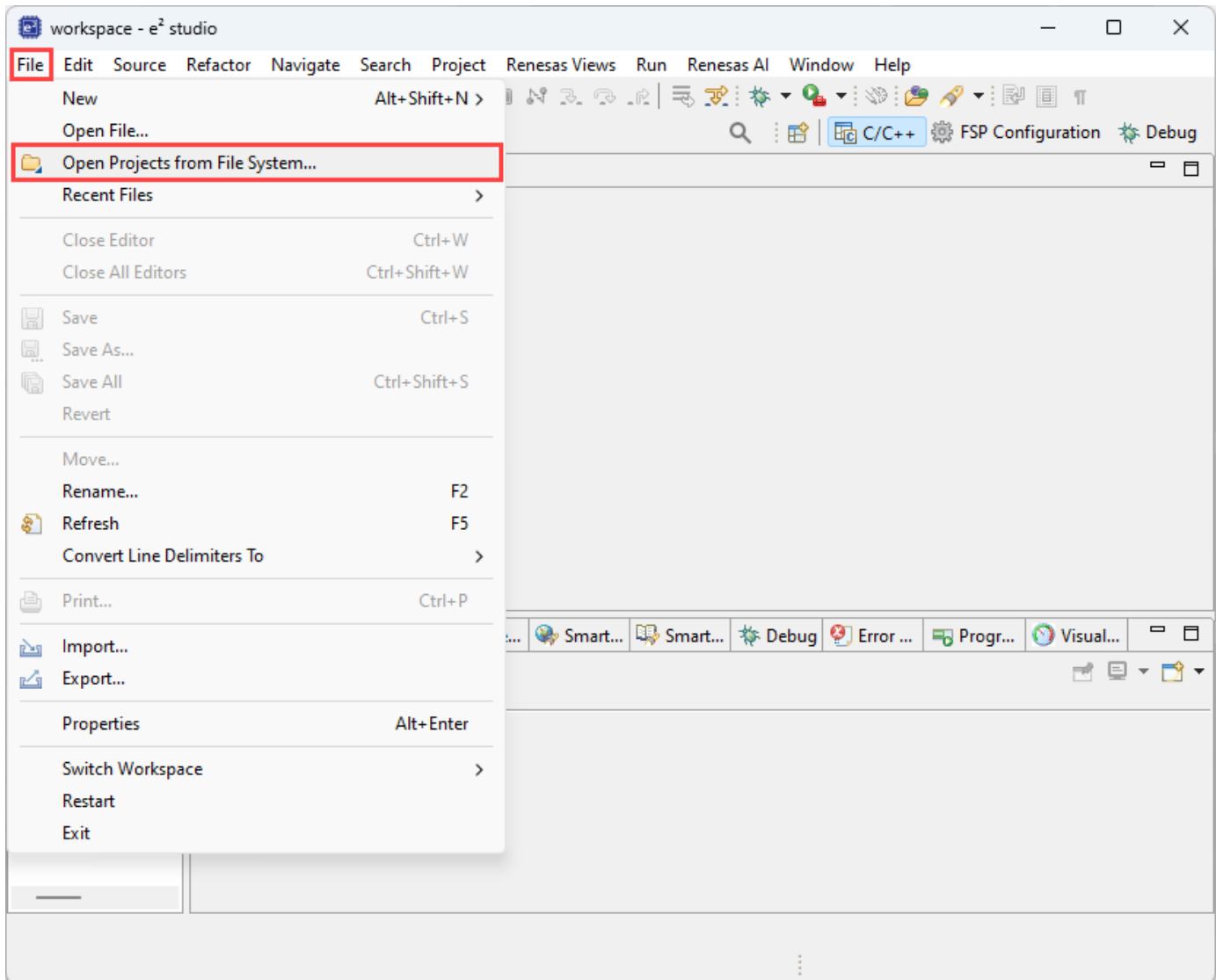
- 1 Simulate the model `SimVbyF.slx` and observe the simulation results. For details, see the section [Simulate Model Containing V/F Control Algorithm](#).
- 2 Click the **Generate code for V/F control** shortcut button to build the model `SimVbyF.slx` as well as generate and save code inside `src` directory available in the `e2StudioProject` folder.



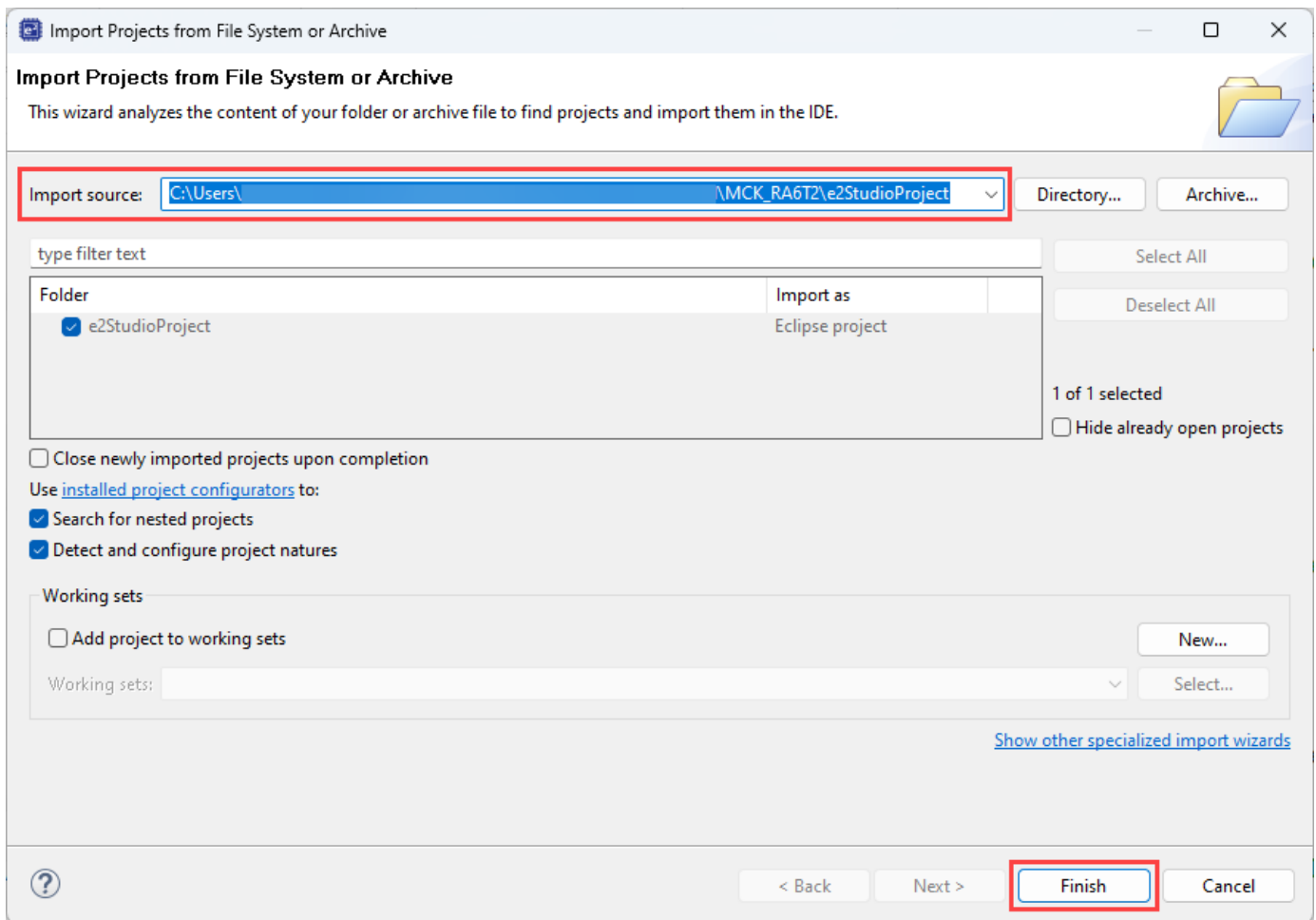
Deploy V/F Control Algorithm Code and Drivers to Hardware

Follow these steps to deploy the generated V/F control algorithm code along with hardware drivers to the MCK-RA6T2 motor control kit using the software e² studio:

- 1 Complete the hardware connections for the MCK-RA6T2 motor control kit (RTK0EMA270S00020BJ) and connect the kit to your computer. For details, see MCK-RA6T2 User's Manual.
- 2 Open the e² studio software.
- 3 Use the menu **File > Open Projects from File System** to open the **Import Projects from File System or Archive** window.

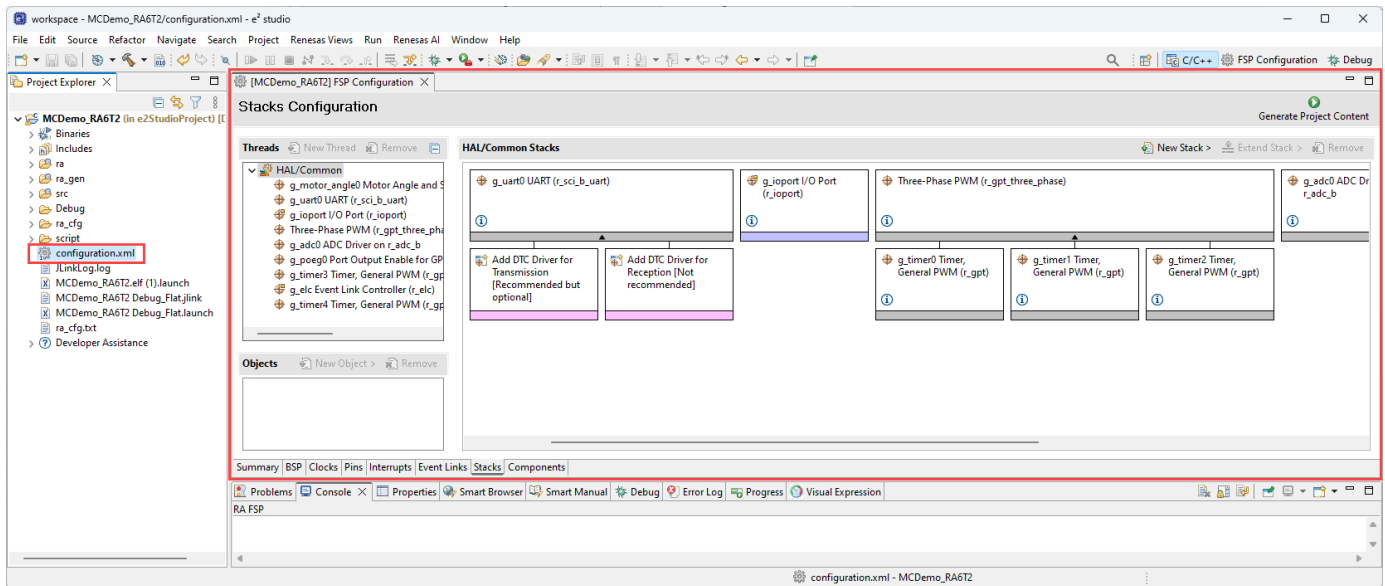


- 4 Use the **Import source** field to navigate to the e2StudioProject directory available in the unzipped folder MCK_RA6T2 and then click **Finish**.

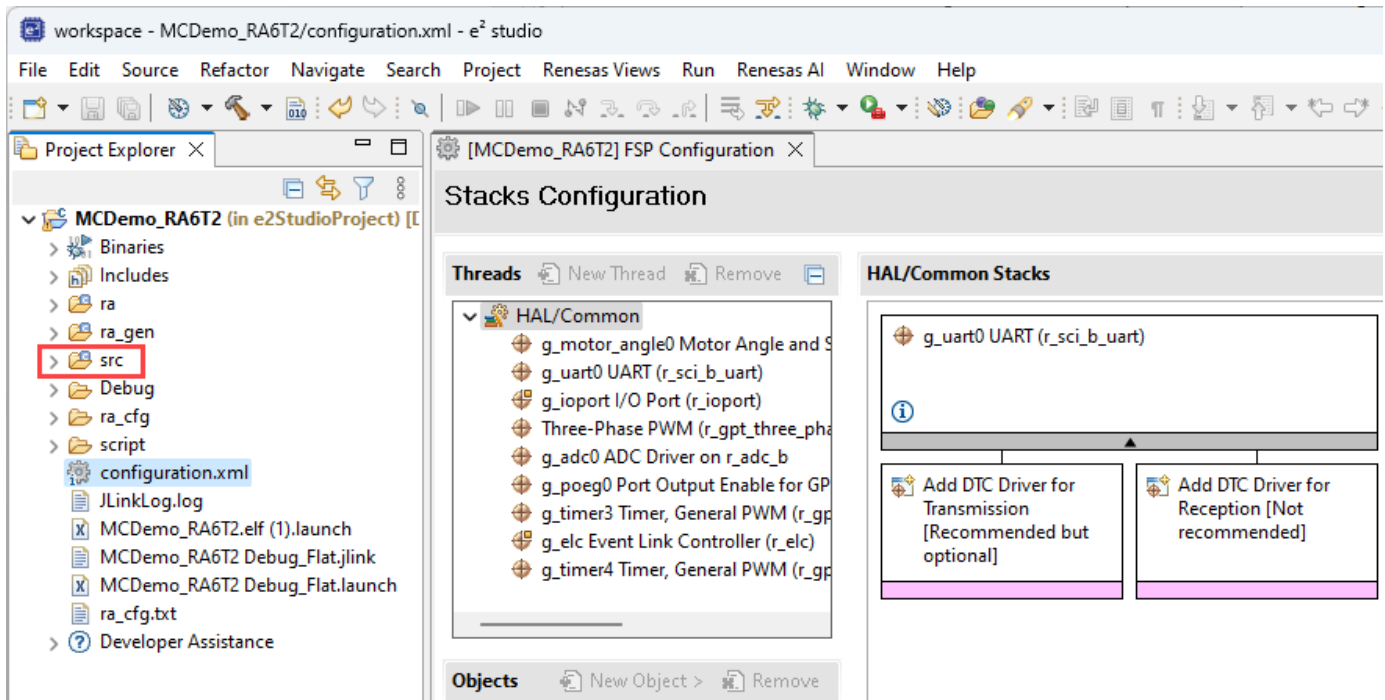


The software opens the Renesas hardware project for MCK-RA6T2 motor control kit in the **Project Explorer** panel.

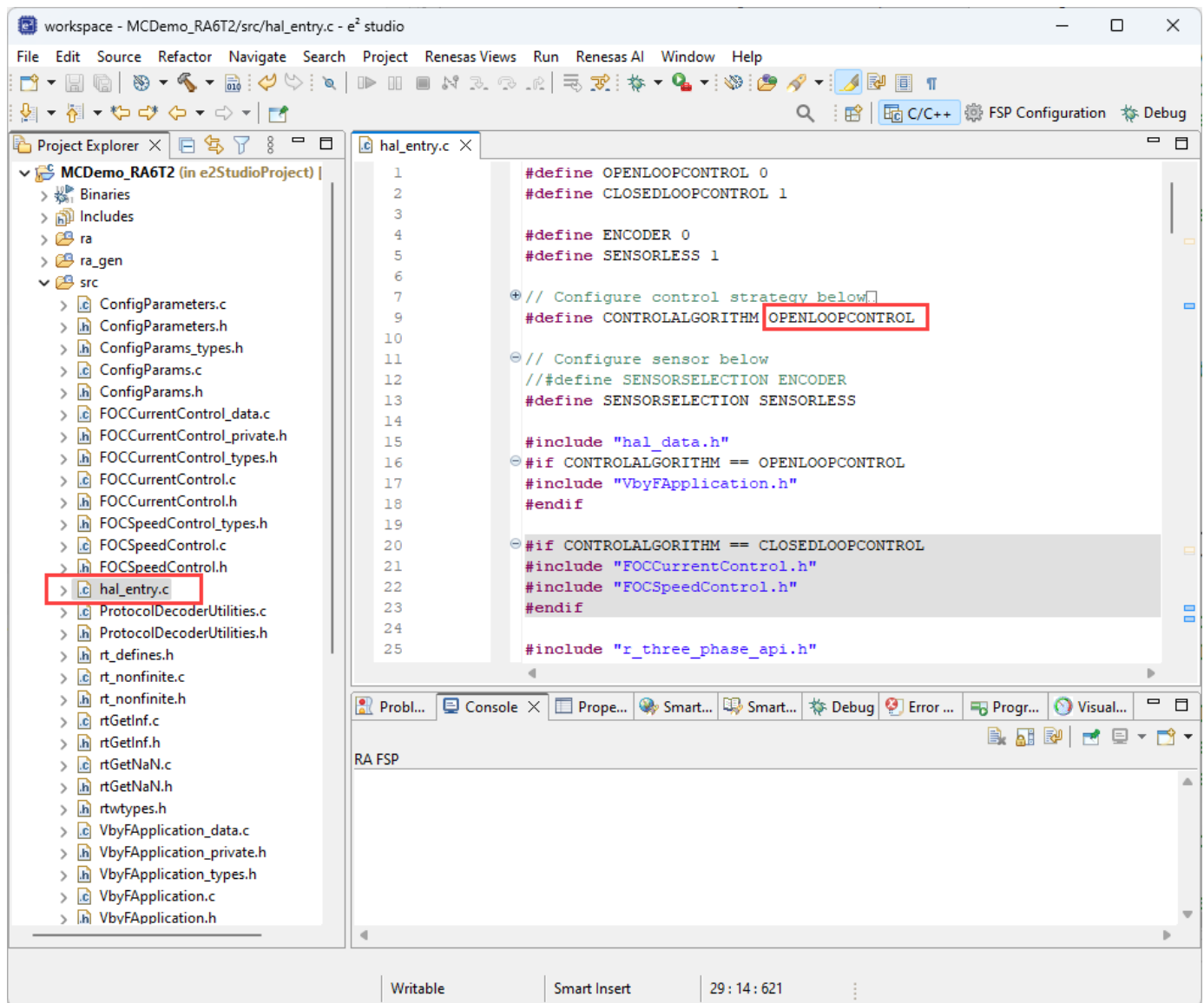
The driver package for the MCK-RA6T2 motor control kit is configured in the file `configuration.xml` as shown in the following figure.



- 5 In the **Project Explorer** panel, expand the folder **src** to open its contents.

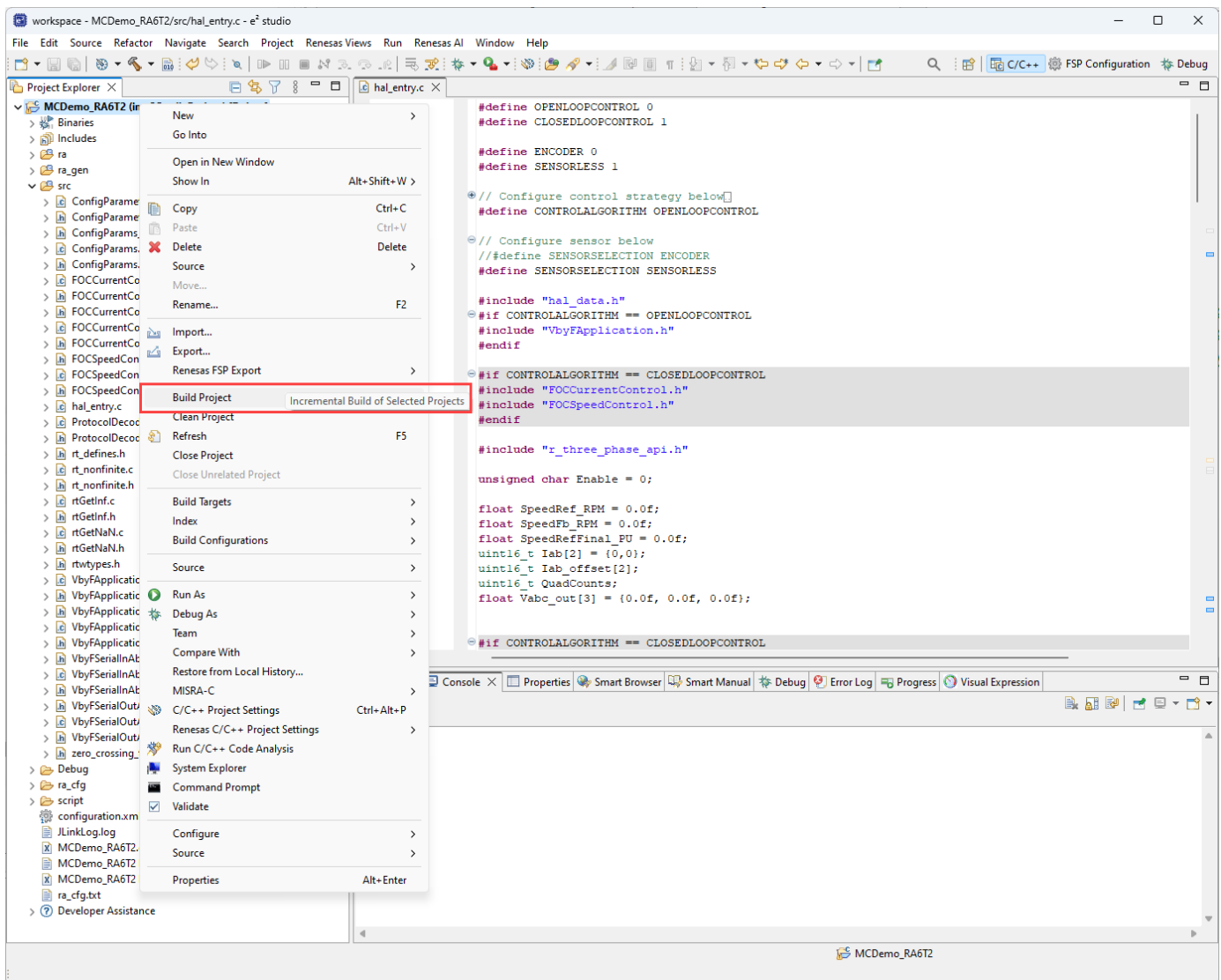


- 6 In the **src** folder, double-click the file **hal_entry.c** to open it in the editor.
- 7 Set the macro **CONTROLALGORITHM** to **OPENLOOPCONTROL** as shown in the following figure.

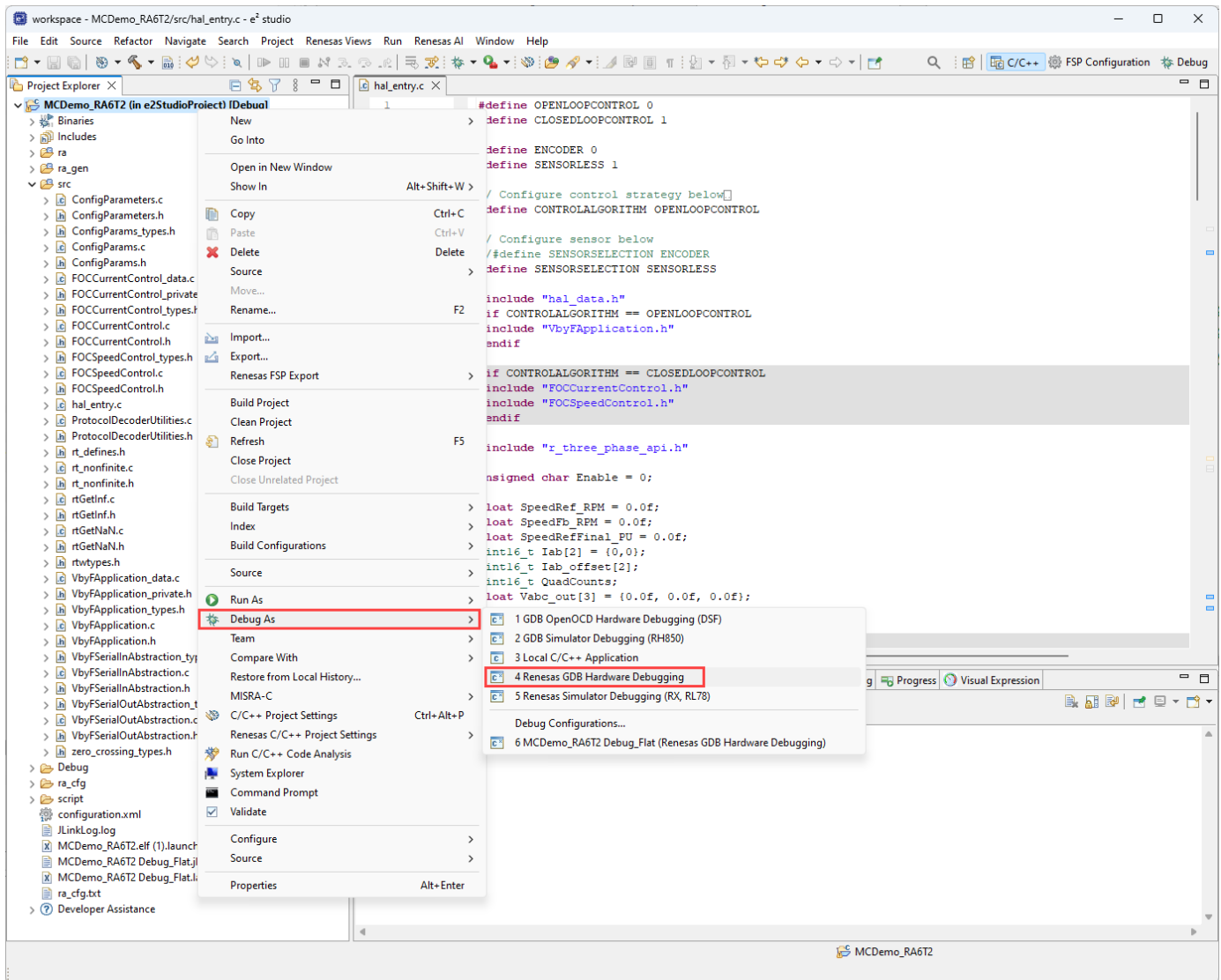


Save the file **hal_entry.c**.

- 8 In the **Project Explorer** panel, right-click the top-level folder **MCDemo_RA6T2** and select **Build Project** to build object code for the V/F control algorithm and hardware drivers.

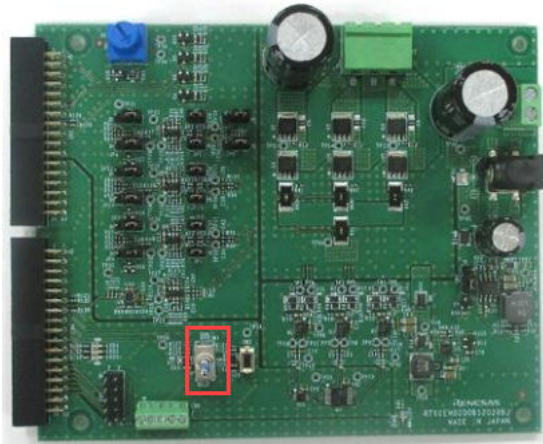


- 9 In the **Project Explorer** panel, right-click the top-level folder **MCDemo_RA6T2** and select **Debug As > 4 Renesas GDB Hardware Debugging** to deploy the object code for the V/F control algorithm and hardware drivers to the MCK-RA6T2 motor control kit.

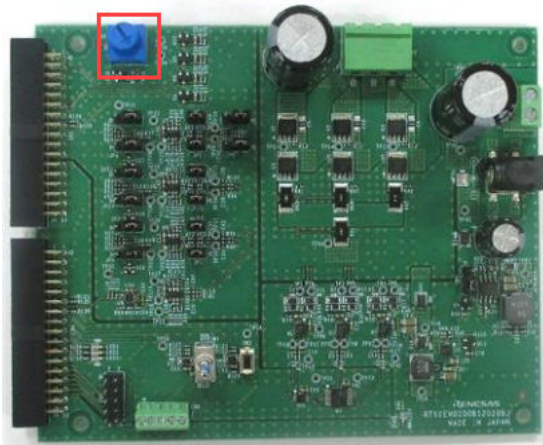


10 In the e2 studio software toolbar, click the **Run** button to start running the deployed code.

11 On the inverter board, turn the toggle switch to ON position to start running the motor.



- 12** During code execution on hardware, you can use the following pot (or dial) on the inverter board to change the reference speed for the V/F control algorithm.



- 13** To stop running the motor turn the toggle switch on the inverter board to OFF position.

Note

- You can safely disconnect the MCK-RA6T2 motor control kit from the computer after completing step 10.
 - After you disconnect the kit from the computer, the deployed code stays on the kit and resumes execution even when you disconnect and reconnect the kit power supply.
-

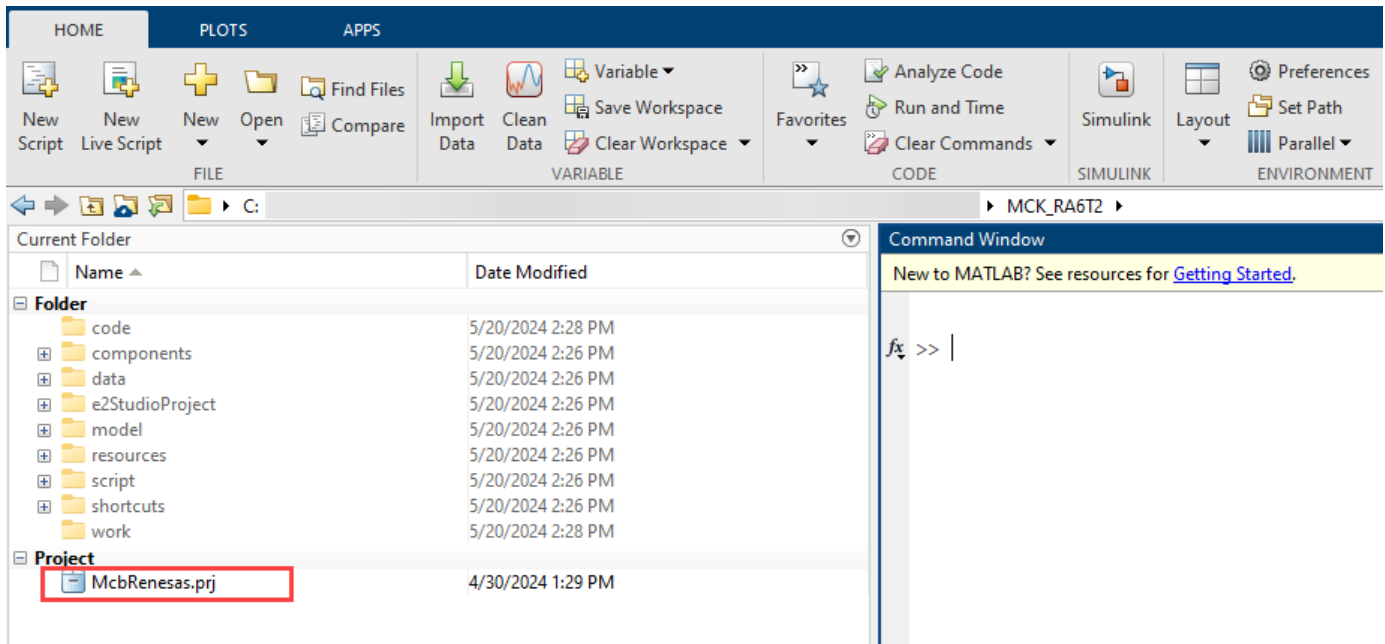
Field-Oriented Control (FOC) of PMSM Using Renesas Hardware

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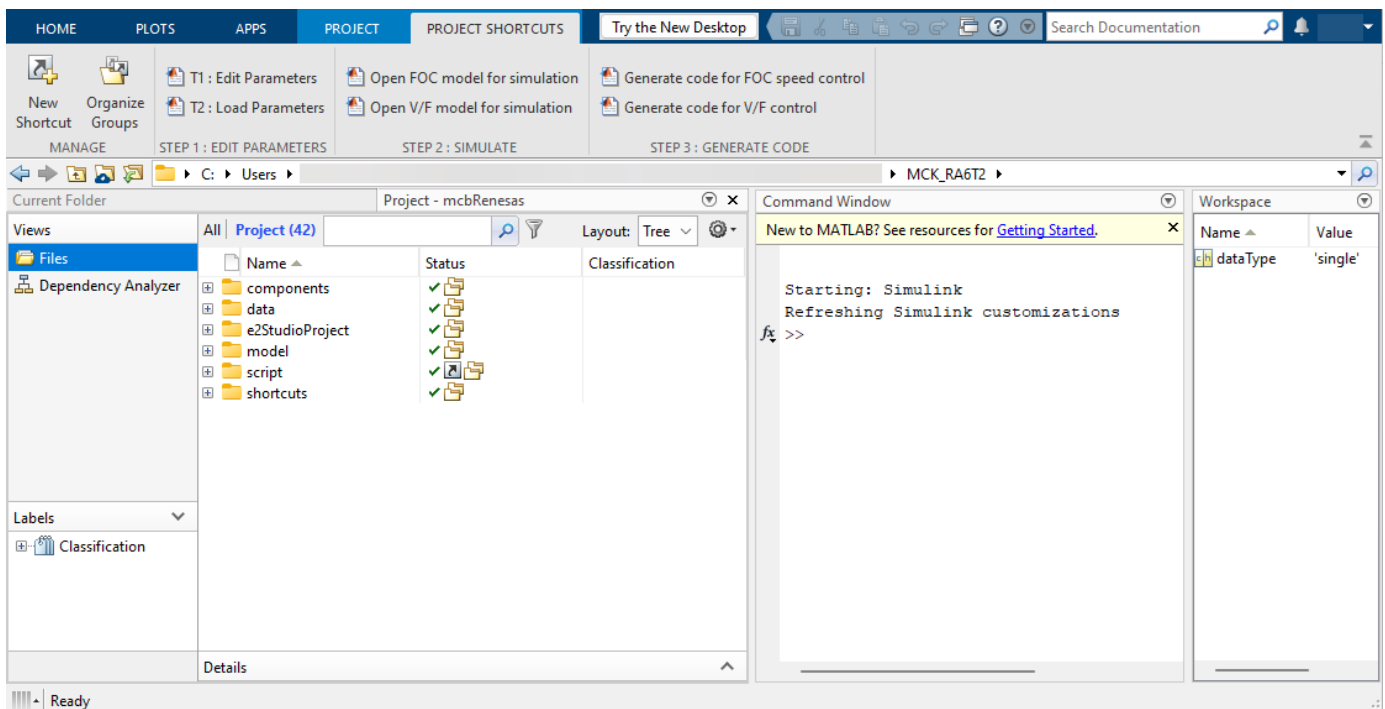
Open MATLAB Project

Follow these steps to open the MATLAB project associated with this example:

- 1 Unzip the MCK_RA6T2.zip folder that you downloaded from the GitHub repository.
- 2 Open MATLAB and navigate to the folder you unzipped in step 1.



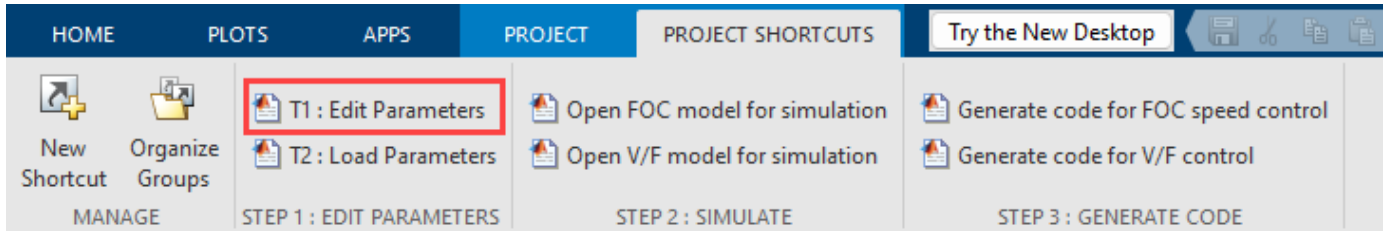
- 3 Double-click the file McbRenesas.prj to open the following MATLAB project window.



Update Motor and Inverter Parameters

The prerequisite to simulating or deploying the Simulink model containing FOC algorithm is to edit the motor and inverter parameters and load them to MATLAB base workspace. Follow these steps to update and load the parameters:

- 1 In the **Project Shortcuts** tab of the MATLAB project window, click the **T1: Edit Parameters** shortcut button to open the model initialization script `EnterParameters.m`.



The Simulink model uses this script to obtain the motor, inverter, and other parameter values, which it uses to compute the derived parameters.

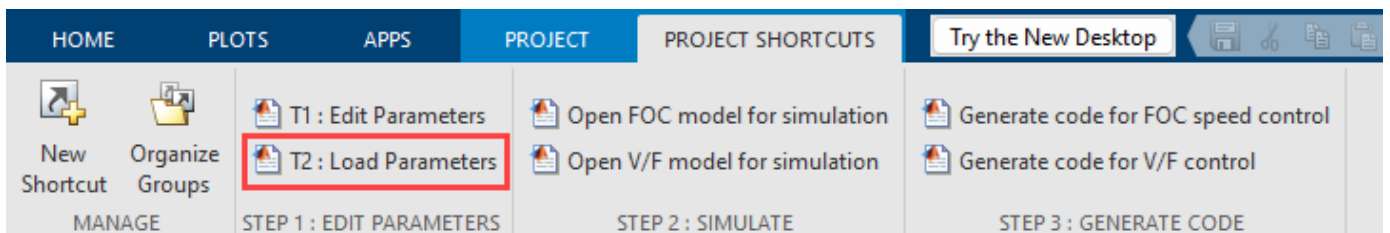
- 2 Update the following sections of the model initialization script `EnterParameters.m`:
 - **Control Loop Frequencies**
 - **Inverter Parameters**
 - **Motor Parameters**

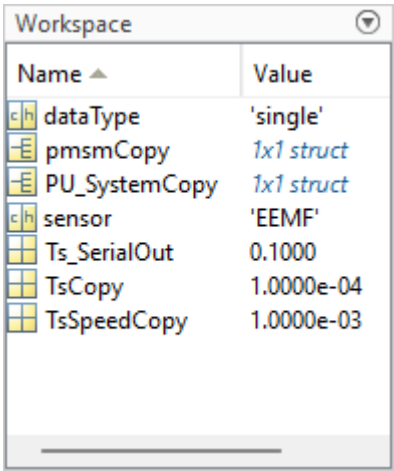
```

Current Folder: Project - mcbRenesas Editor - EnterParameters.m
EnterParameters.m
1 %% Control loop frequencies
2 fCurrentControl = 10e3; % Hz
3 fSpeedControl = fCurrentControl/10; % Hz
4
5 target.PWM_frequency = 10e3; % Hz % The frequency configuration must be done in driver code too
6
7 %% Inverter Parameters
8 inverter.V_dc = 24; % V
9 inverter.ISenseMax = 8.25; % A % Maximum current sensed by inverter
10 inverter.R_board = 0.0033; % ohm % Rds_ON + Rshunt/3
11
12 %% Motor Parameters
13 pmsm.p = 4; % Pole pairs
14 pmsm.I_rated = 1.6; % A
15 pmsm.N_rated = 3500; % RPM
16 pmsm.T_rated = 0.1; % Nm
17 pmsm.QEPSlits = 1000; % Quadrature encoder slits
18 pmsm.Rs = 0.75; % ohm
19 pmsm.Ld = 0.5e-3; % H
20 pmsm.Lq = 0.5e-3; % H
21 pmsm.Ke = 7; % Vpk_LL/kRPM
22 pmsm.J = 8e-6; % Kg-m2
23 pmsm.B = 8e-5; % Kg-m2/s
24 pmsm.V_boost = 0.15; % PU volt
25
26 %% Sensor selection
27 sensor = 'EEMF'; % 'Encoder' , 'EEMF'
28
29 %% Derived Parameters
30 T_pwm = 1/target.PWM_frequency;
31 Ts = 1/fCurrentControl;
32 Ts_speed = 1/fSpeedControl;
33 Ts_motor = Ts/2;
34
35 Ts_SerialOut = 0.1; % Required only for UART
36
37 pmsm.FluxPM = (pmsm.Ke)/(sqrt(3)*2*pi*1000*pmsm.p/60);
38 pmsm.N_base = mcb_getBaseSpeed(pmsm,inverter);
39 PU_System = mcb_SetPUSystem(pmsm,inverter);
40 PI_params = mcb_SetControllerParameters(pmsm,inverter,PU_System,T_pwm,Ts,Ts_speed);
41
42 % Create copies for EEMF block as the parameters are not tunable

```

- 3 Click **Save** to save the file EnterParameters.m.
- 4 Switch to the MATLAB project window and navigate to the **Project Shortcuts** tab.
- 5 Click the **T2: Load Parameters** shortcut button to:
 - Compute derived parameters using the data available in the model initialization script.
 - Update all parameters to the Simulink data dictionary motorControlData.sldd.
 - Load necessary parameters from Simulink data dictionary to the MATLAB base workspace.





The screenshot shows the MATLAB Workspace window with a table of variables. The table has two columns: 'Name' and 'Value'. The variables listed are: dataType (single), pmsmCopy (1x1 struct), PU_SystemCopy (1x1 struct), sensor (EEMF), Ts_SerialOut (0.1000), TsCopy (1.0000e-04), and TsSpeedCopy (1.0000e-03). Each variable name has a small icon to its left, and the values are displayed in a blue font.

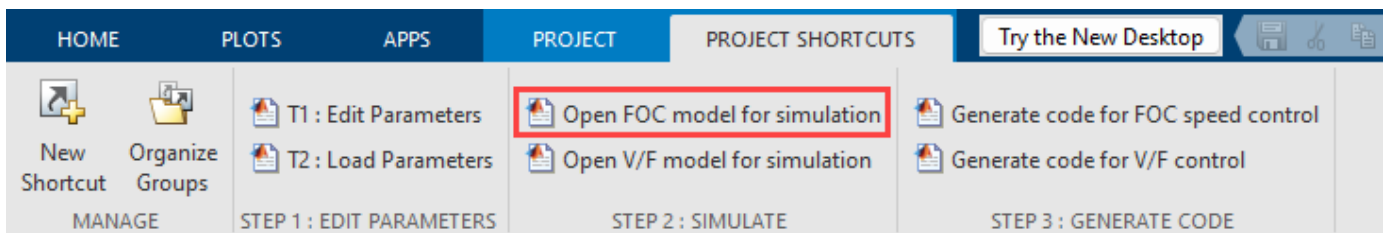
Name ▲	Value
dataType	'single'
pmsmCopy	1x1 struct
PU_SystemCopy	1x1 struct
sensor	'EEMF'
Ts_SerialOut	0.1000
TsCopy	1.0000e-04
TsSpeedCopy	1.0000e-03

Note The shortcut **T2: Load Parameters** loads only the necessary parameters to the base workspace. The Simulink model reads the other parameters directly from the Simulink data dictionary.

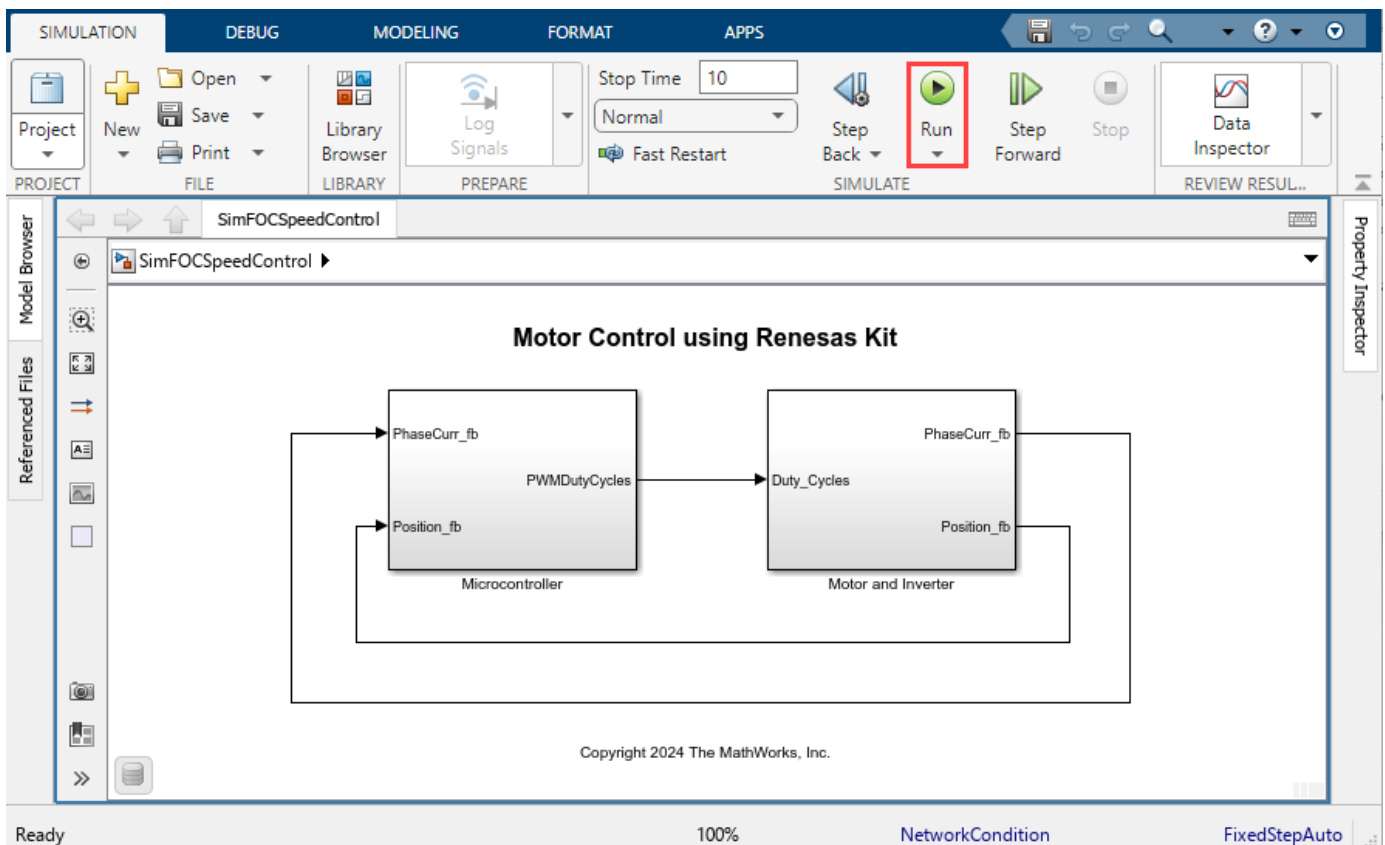
Simulate Model Containing FOC Algorithm

This example supports simulation. Follow these steps to simulate the Simulink model containing the FOC speed control algorithm.

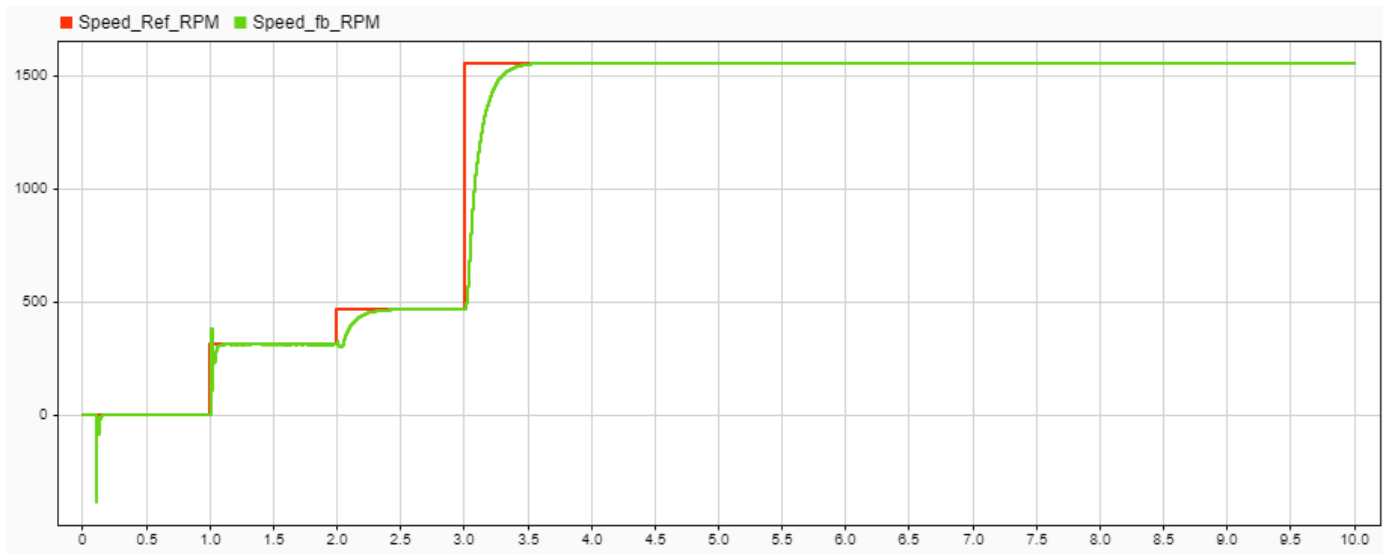
- 1 Ensure that you edit the motor and inverter parameters and load them to the MATLAB base workspace. For details, see the section Update Motor and Inverter Parameters.
- 2 In the **Project Shortcuts** tab of the MATLAB project window, click the **Open FOC model for simulation** shortcut button to open the Simulink model `SimFOCSpeedControl.slx` containing the FOC speed control algorithm.



- 3 Click **Run** on the **Simulation** tab to simulate the model.



- 4 Click **Data Inspector** on the **Simulation** tab to view and analyze the simulation results.

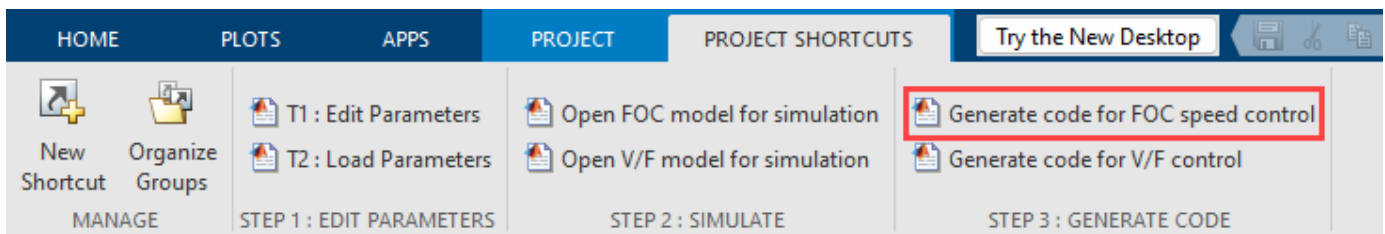


Generate Code for FOC Algorithm

This section explains how to use the Simulink model `SimFOCSpeedControl.slx` to generate code for the FOC speed control algorithm.

Follow these steps to generate the code:

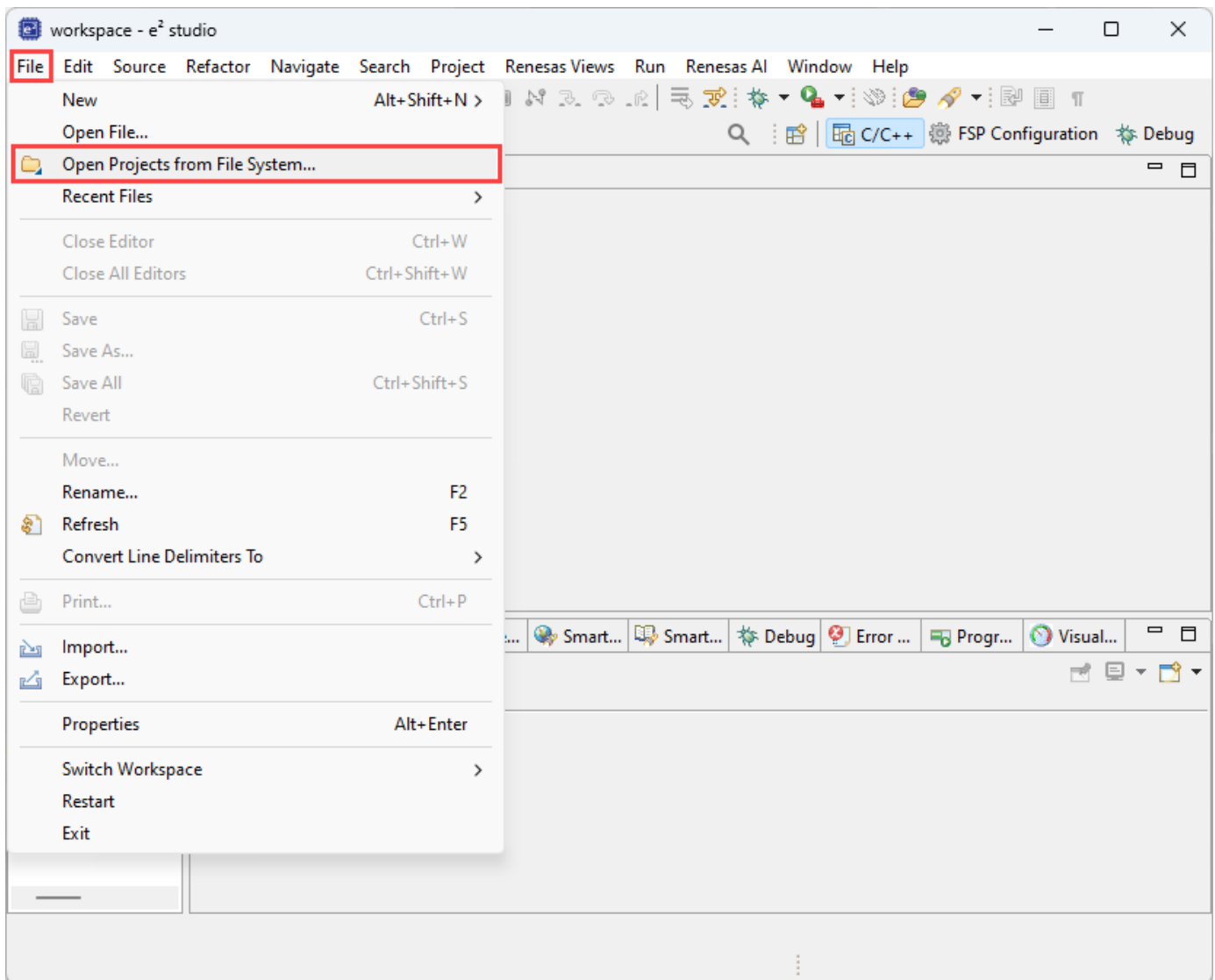
- 1 Simulate the model `SimFOCSpeedControl.slx` and observe the simulation results. For details, see the section [Simulate Model Containing FOC Algorithm](#).
- 2 Click the **Generate code for FOC speed control** shortcut button to build the model `SimFOCSpeedControl.slx` as well as generate and save code inside `src` directory available in the `e2StudioProject` folder.



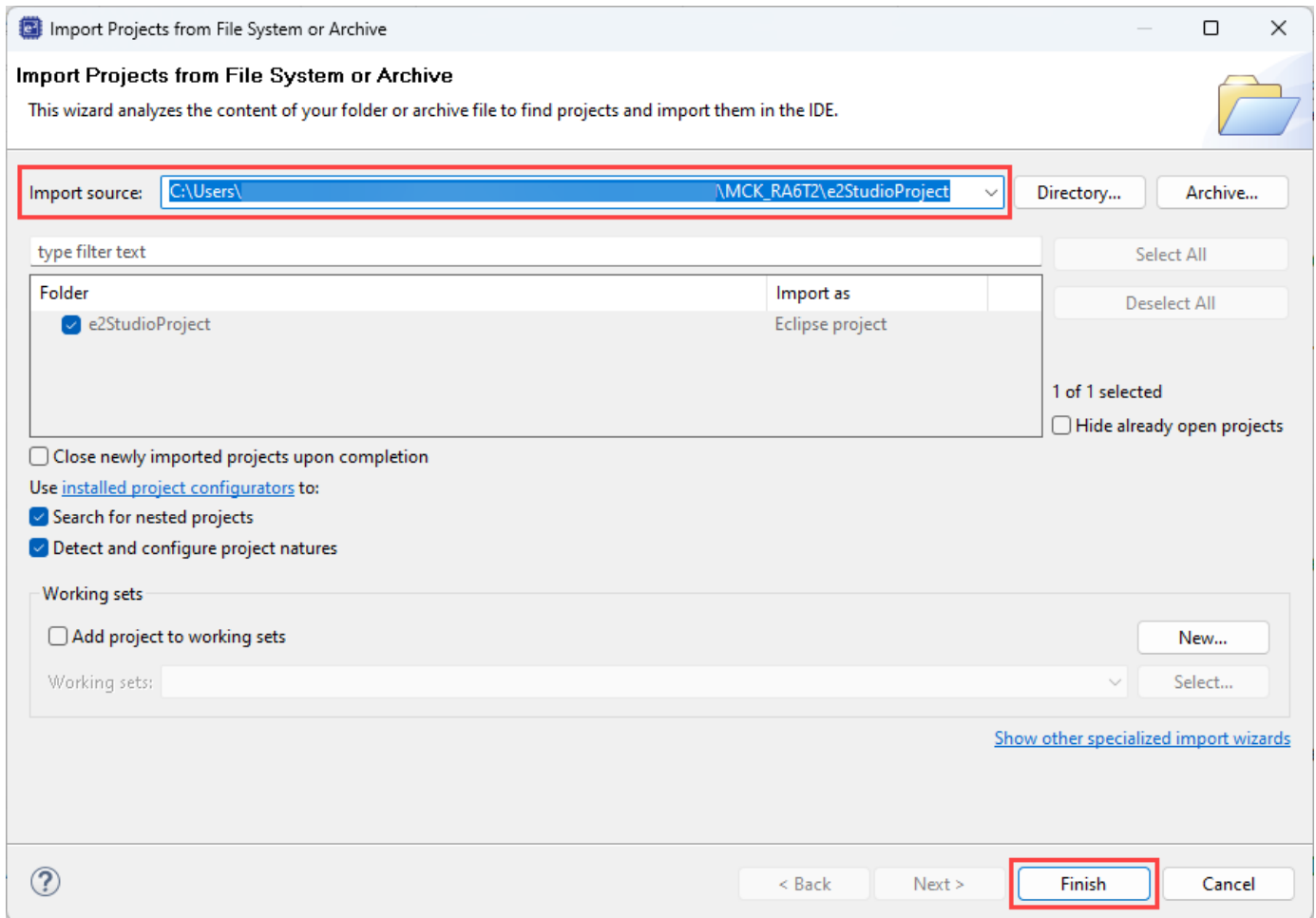
Deploy FOC Algorithm Code and Drivers to Hardware

Follow these steps to deploy the generated FOC speed control algorithm code along with hardware drivers to the MCK-RA6T2 motor control kit using the software e² studio:

- 1 Complete the hardware connections for the MCK-RA6T2 motor control kit (RTK0EMA270S00020BJ) and connect the kit to your computer. For details, see MCK-RA6T2 User's Manual.
- 2 Open the e² studio software.
- 3 Use the menu **File > Open Projects from File System** to open the **Import Projects from File System or Archive** window.

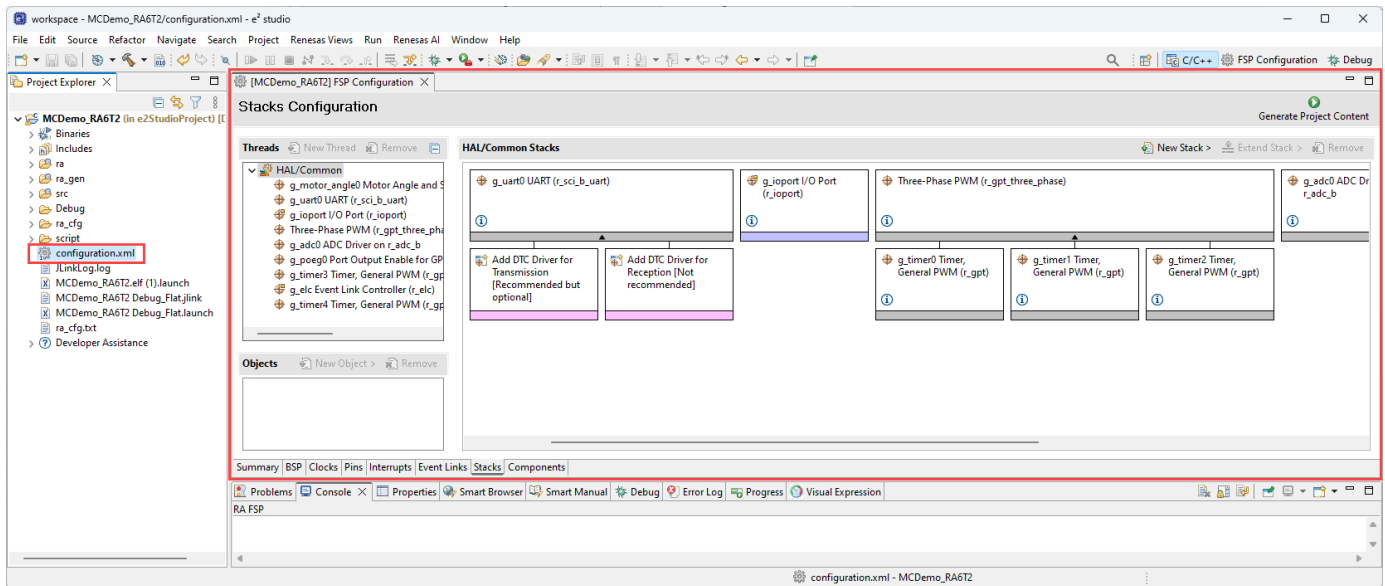


- 4 Use the **Import source** field to navigate to the e2StudioProject directory available in the unzipped folder MCK_RA6T2 and then click **Finish**.

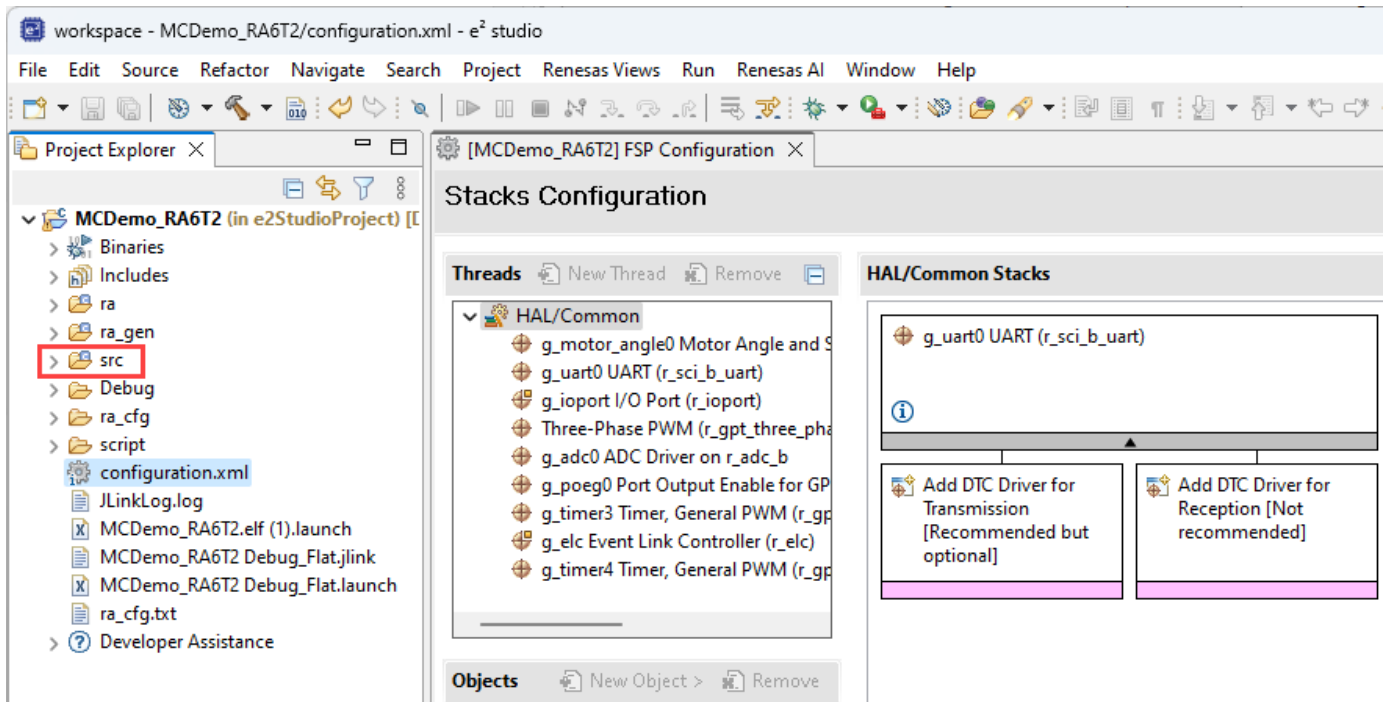


The software opens the Renesas hardware project for MCK-RA6T2 motor control kit in the **Project Explorer** panel.

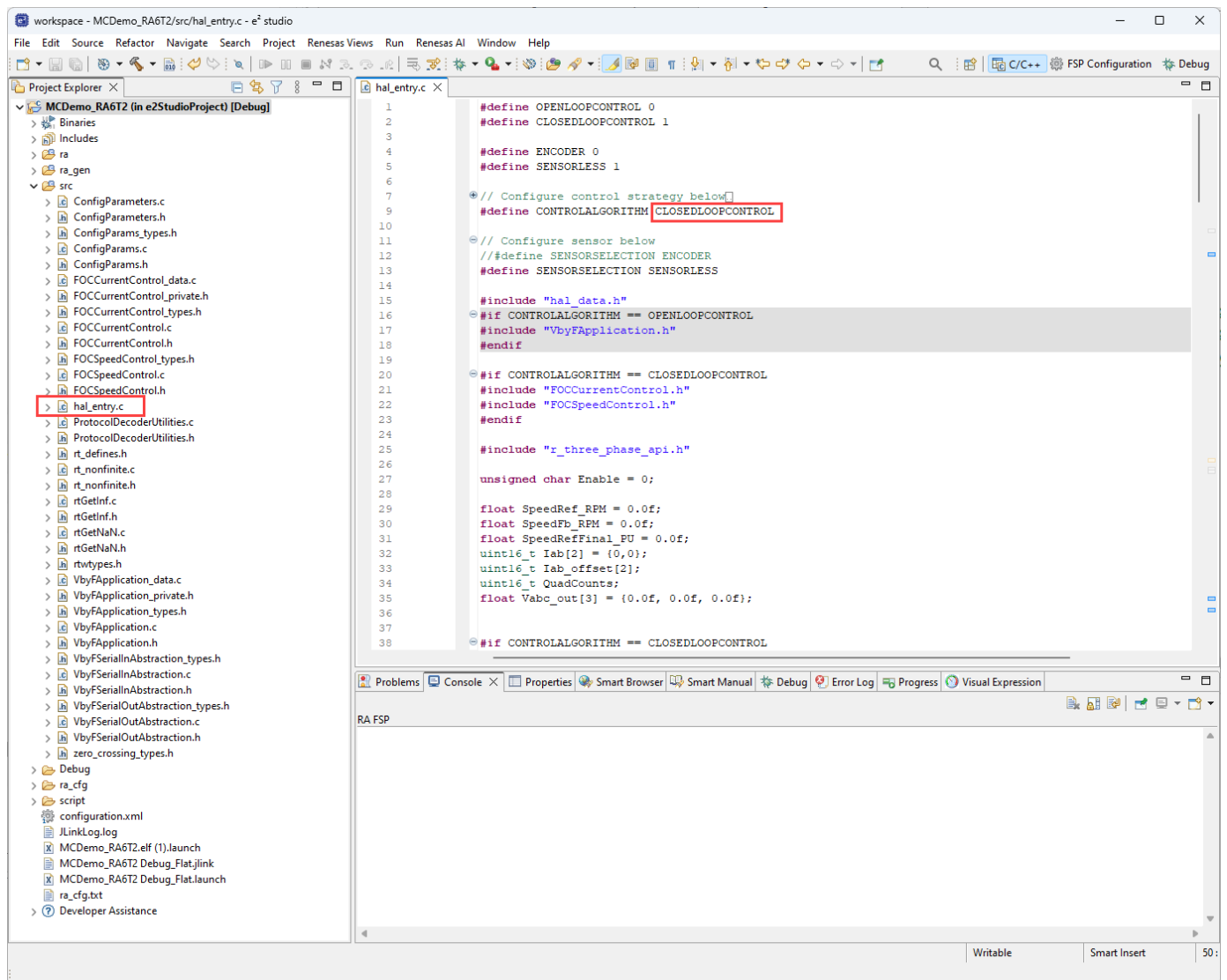
The driver package for the MCK-RA6T2 motor control kit is configured in the file `configuration.xml` as shown in the following figure.



- 5 In the **Project Explorer** panel, expand the folder **src** to open its contents.

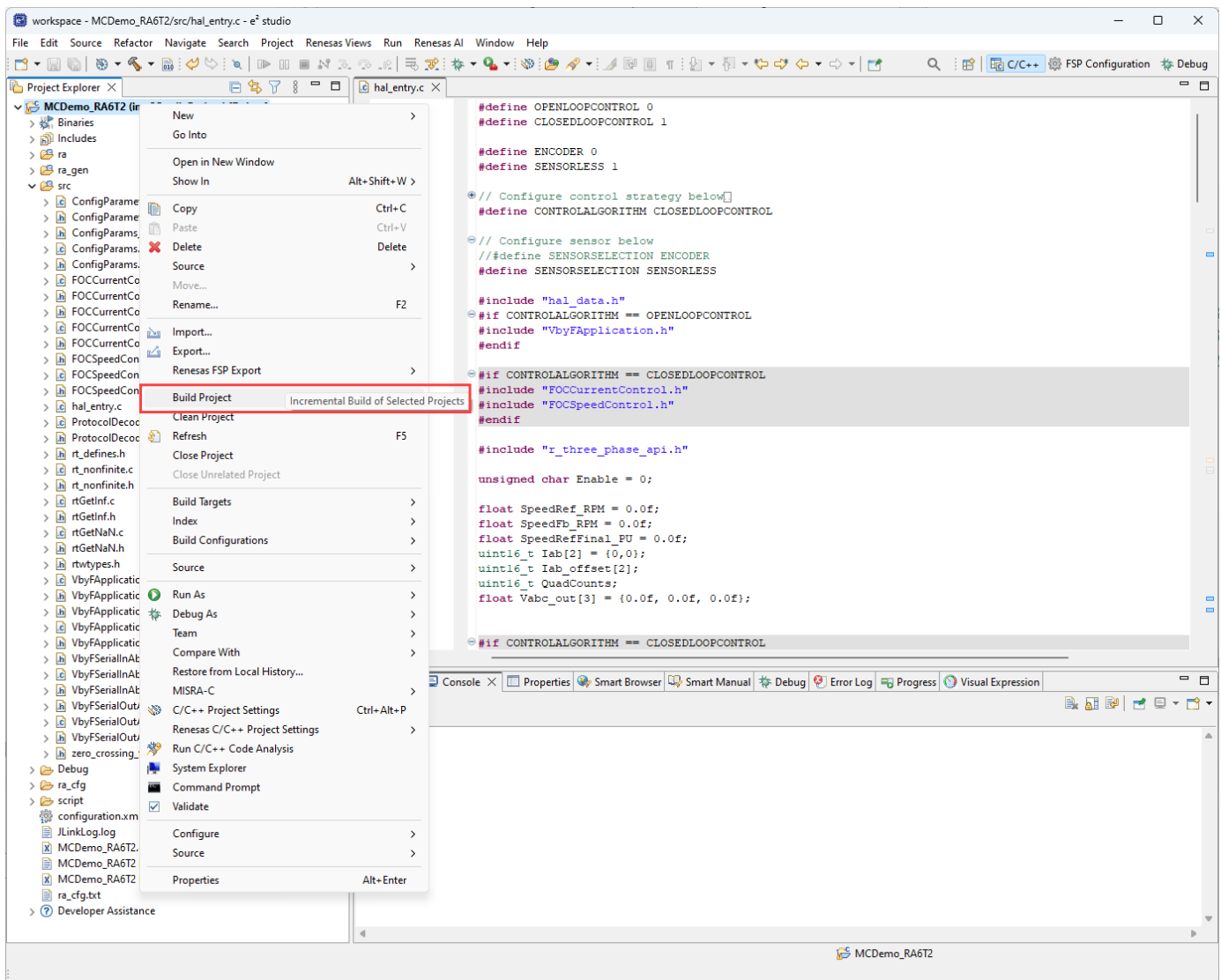


- 6 In the **src** folder, double-click the file **hal_entry.c** to open it in the editor.
- 7 Set the macro **CONTROLALGORITHM** to **CLOSEDLOOPCONTROL** as shown in the following figure.

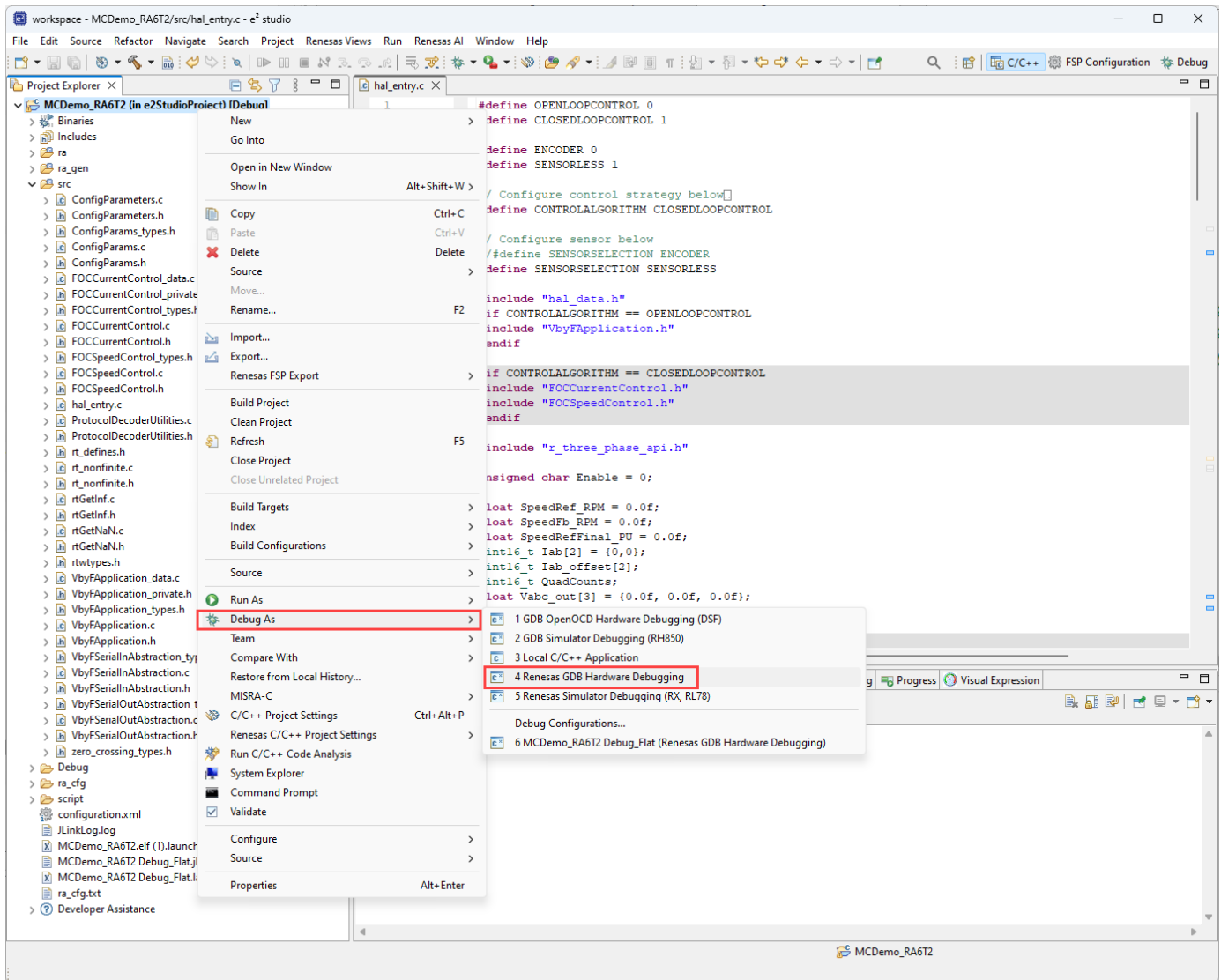


Save the file `hal_entry.c`.

- 8 In the **Project Explorer** panel, right-click the top-level folder `MCDemo_RA6T2` and select **Build Project** to build object code for the FOC algorithm and hardware drivers.

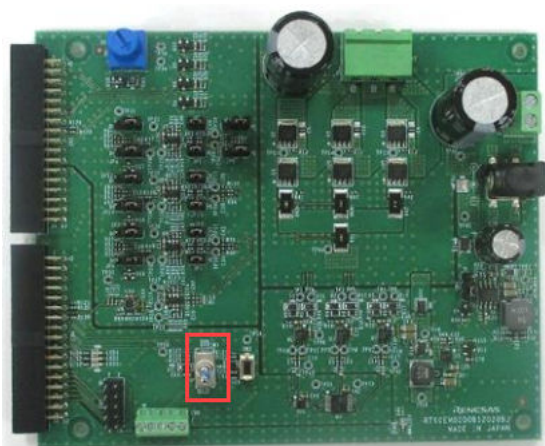


- 9 In the **Project Explorer** panel, right-click the top-level folder **MCDemo_RA6T2** and select **Debug As > 4 Renesas GDB Hardware Debugging** to deploy the object code for the FOC algorithm and hardware drivers to the MCK-RA6T2 motor control kit.

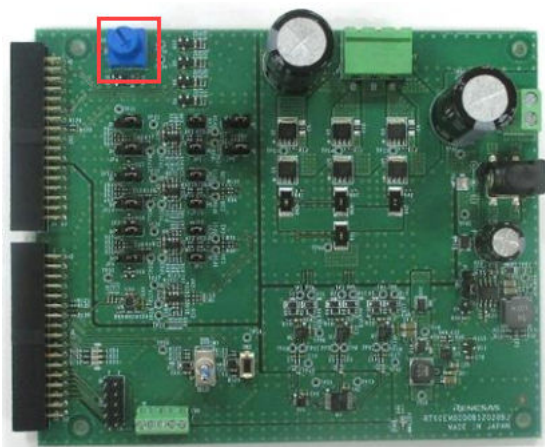


10 In the e2 studio software toolbar, click the **Run** button to start running the deployed code.

11 On the inverter board, turn the toggle switch to ON position to start running the motor.



- 12** During code execution on hardware, you can use the following pot (or dial) on the inverter board to change the reference speed for the FOC algorithm.



- 13** To stop running the motor turn the toggle switch on the inverter board to OFF position.

Note

- You can safely disconnect the MCK-RA6T2 motor control kit from the computer after completing step 10.
 - After you disconnect the kit from the computer, the deployed code stays on the kit and resumes execution even when you disconnect and reconnect the kit power supply.
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